LOSSY MODEL OF DIODE PACKAGES: AN ALTERNATIVE METHOD FOR EXACT EVALUATION OF ACTIVE CHIP PARAMETERS

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ABSTRACT

A systematic method of obtaining accurate models of microwave active device packages is reported. Using a set of offset shorts as coaxial line extensions the effect of the lossy elements of the package can be determined with high accuracy. In the next step encapsulated varactor diode chips are investigated. The Q factor of the encapsulated device calculated by applying the model to experimental measurements shows a high degradation depending on the ratio of the package parasitics to the device parameters. Experimental results compared with calculated model show good agreement up to 20 GHz on S4 type packages.

INTRODUCTION

Modern microwave automatic vector network analyzer (VANA) measurement technique, providing a large amount of measured data over a wide band with high accuracy, speed and convenience has resulted in the necessity to revise some of the results of the previous methods or models. The intention of this work is to include lossy elements which have previously been ignored.

In the literature only a very few articles deal with package losses (e.g. 1), but the proposed model is not satisfactory. Others (2, 3) obtained different values for the same elements by using slightly different methods. Also the values varied depending on the package manufacturer. It seems to be that the methods are not sensitive enough to be able to obtain accurate values. So, it is not surprising that "significant differences are observed when the package is reversed" (3, p.796), or "the inductance depends on the coaxial–line dimensions".

The aim of the present work was the evaluation of the package equivalent circuits having lossy elements and in this way the exact determination of chip parameters became also possible.

BASIC MEASUREMENT METHOD

Taking the advantages of a modern VANA system, semiconductor device packages have been measured in a set of very simple, broadband 50 Ohm coaxial offset shorts with APC–7 connectors. The packages have been substituted for the inner conductor of the coaxial line as in Fig.1. We have measured all of the packages with different bonding configurations in four different positions as follows:

A. the package is located with its cap looking into the direction of the reference plane of the VANA,

B. and opposite to this.

Both A and B positions were checked using a shorter (1.8 mm) and a longer (11.0 mm) section of extension line terminated by a short.

This redundant method was found to be very useful in improving the accuracy of the measurement. To achieve the most accurate model of the package, first a piece of coaxial line was measured in the place of the package, this was then replaced by an empty package and finally open and short circuited packages were measured with different bonding configurations. With this procedure we

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evaluate the elements of the model step-by-step. Also, in this way the role of each element remains separate and clear, which is one of the advantages of this technique. The measurements were repeated with 3 individual sets of packages.

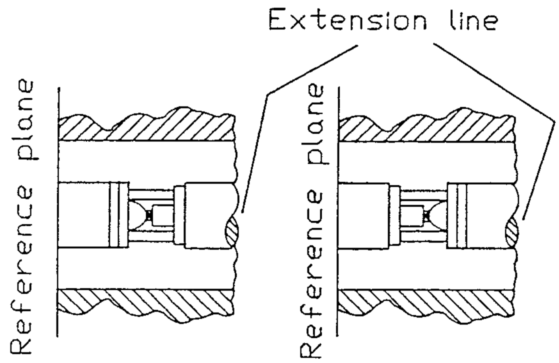

Fig.1

The accuracy of the calibration of the VANA was always better than 0.01 in magnitude and 0.5 degree in phase. The repeatability of the re-mounting (i.e. the same package and the same calibration) was better than the above mentioned value. The results obtained from individual packages with the same bonding structures have an uncertainty of less than 0.015 in magnitude and 1 degree in phase, mostly because of the ± 0.03 mm scattering of the dimensions of the packages.

PACKAGE MODEL

To evaluate the accurate package model the step-by-step method is as follows. As a first step the offset shorts with an extension line were measured to check the method and determine the small losses of the offset shorts and the transmission line. The second step was to replace the inner conductor of the coaxial extension line with the "empty" package. Starting from the model in Fig.2 we have calculated the best values of the elements. C_1 and C_2 are the fringing capacitances of the change in the diameter of the inner conductor of the transmission line, L_1 and R_1 are the inductivity of the heat sink and the assumed loss, respectively, and C_3 and C_4 are the capacitances between the cap of the package and the bottom and top of the heat sink, respectively. The results show that $C_3 \approx 0$ and $R_1 \approx 0$, so the "empty" package has no significant loss. Other components are:

$$C_1 = 0.050 \text{ pF};\ C_2 = 0.045 \text{ pF};$$
$$L_1 = 0.520 \text{ nH};\ C_4 = 0.210 \text{ pF}.$$

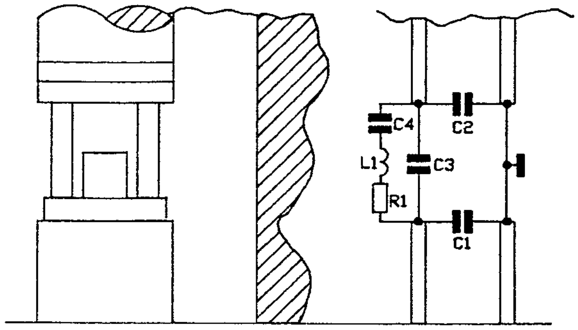

Fig.2

The next step was to check the influence of the wire in the "open" circuit package. The "open" circuit package was produced by allowing a 25 μm diameter wire to hang as closely as possible to the post without making contact. The difference between "empty" and "open" packages was found to be negligible, and this is because no current occurs in the wire.

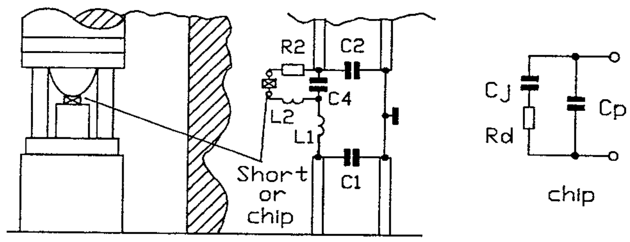

Fig.3

The following step was the measurement of the "short" circuit package, using the values obtained thus far as. The "short" circuit package was produced by bonding the wire directly onto the post. After obtaining on accurate value of L_2, the final step is to determine the value of the loss R_2, which is strongly dependent on the bonding and not equal to zero. In Fig.3 the final package model can be seen ($L_2 = 0.410$ nH and $R_2 = 0.3$ Ohm) with a varactor chip equivalent circuit.

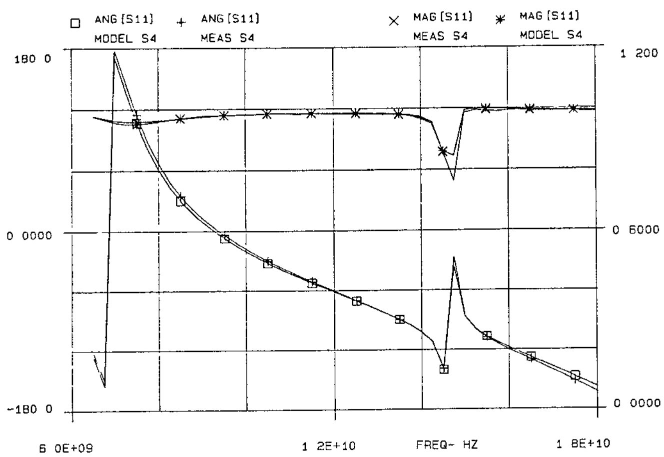

Fig.4

Fig.4 illustrates the phase and amplitude accuracy obtained for package with short circuit at the place of the chip.

THE LOSSES

For the determination of the chip equivalent circuit the effect of the bonding wires is also needed. The value of the element in the equivalent circuit describing the lossy effect of wires is very small, so to obtain this element is rather complicated. The fixtures described in the literature (see Introduction) all put the package at the very bottom of the fixture. In this way because of the small package loss of only a few tenths of one Ohm the magnitude of S_{11} for the measured package only slightly differs from one. The effect seems to conceal the package losses.

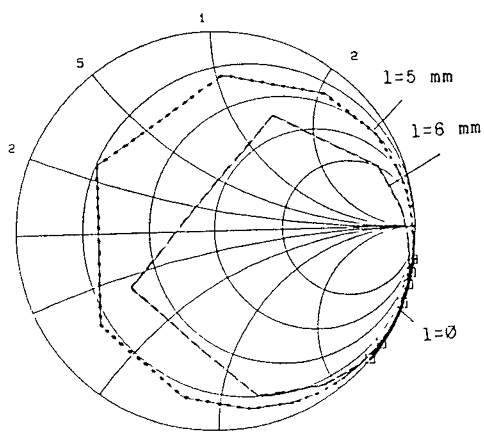

Fig.5

In our method using an ideal waveguide or coaxial line extension with it's proper length as a "transformer" placed behind the package the effect of the losses on the S-parameters can be "amplified". This can be calculated (see Appendix). Fig.5 demonstrates the effect of different length of line.

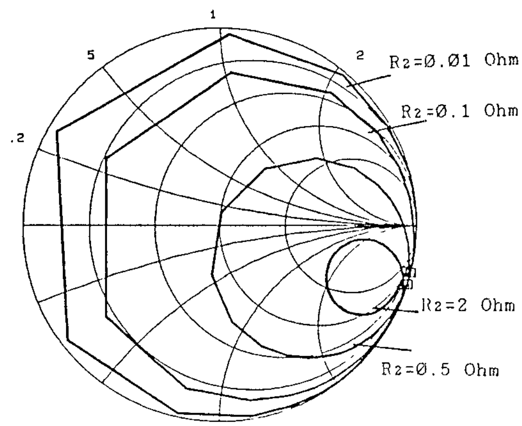

Fig.6

In Fig.6 the results of the calculation carried out for different losses at a given length of line l = 5 mm are shown. The advantage of the described method is that using a simple fixture the resonant frequency of the circuit having losses can be transformed into the measured range. The influence of the length on the accuracy of the elements to be obtained is weak, which is an another benefit.

The inconvenience of the proposed method is that for the evaluation of the length of the waveguide used for the transformation one needs the approximate values of the elements C_2, L_2 and C_4. Using this method a calculation has been carried out for S4 type encapsulation with a gold single wire of diameter 25 μm. The obtained loss is 0.3 Ohm, which can effectively influence the Q factor of a varactor diode.

Experimental results of encapsulated varactor diode compared with the final calculated model show good agreement as it is shown in Fig.7 (left: phase in degrees, right: magnitude; MEAS−4V: measured and MODL−4V: calculated results at − 4 V varactor voltage). The frequency range of measuring and modelling was over a wide band from 0.2 to 20.2 GHz.

The elements are:

Package: C_1; C_2; C_3; C_4; L_1; L_2; R_1 and R_2 (see above)

Varactor chip: $C_j = 1.050$ pF; $C_p = 0.095$ pF; $R_d = 2.50$ Ohm

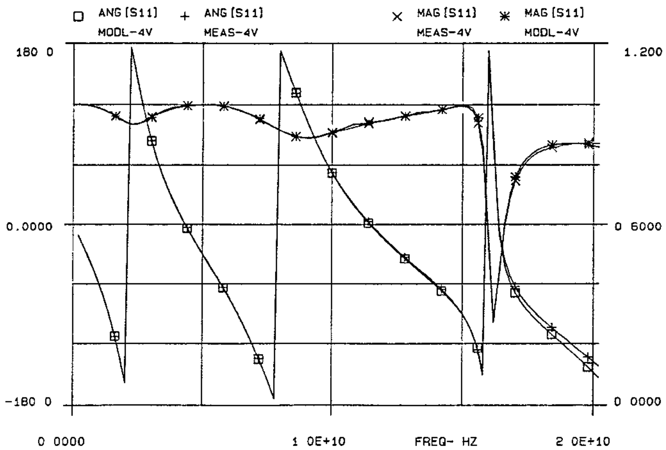

Fig.7

CONCLUSION

A new, straightforward, accurate microwave measurement technique has been reported for the characterization of semiconductor device packages including lossy elements. The ultimate advantage of the method is the promise to have an alternative method where accurate models are prerequisite for the evaluation of active chip parameters.

APPENDIX

Assuming C_1 to be small, its effect as a first approximation can be neglected. Serial elements in the equivalent circuit (R_2; L_1; L_2; C_4 see Fig.3) can be represented by a serial impedance $R + jX$. Where

$$R \approx \frac{R_2}{(\omega^2 L_2 C_4 - 1)^2} \tag{1}$$

and

$$X \approx \omega L_1 + \frac{\omega L_2 - \omega^3 C_4 L_2^2}{(\omega^2 L_2 C_4 - 1)^2} \tag{2}$$

In (1) and (2) the lower order parts of the sums were neglected.

The parallel C_2 and the extension line is written as jK. The aim of the extension is to reduce the magnitude of S_{11} ($|S_{11}| \approx 1$ without extension).

So

$$|S_{11}| < A$$

and

$$\frac{(R - Z_0)^2 + (X + K)^2}{(R + Z_0)^2 + (X + K)^2} < A^2$$

where $Z_0 = 50$ Ohm is the waveguide impedance.

So

$$(X + K)^2 < 2RZ_0 \frac{1+A^2}{1-A^2} - (R^2+Z_0^2) \tag{3}$$

where the left side is always positive, its minimum value is zero when

$$X = -K \tag{4}$$

Solving equations (1) and (3) we can calculate a frequency band where the magnitude of S_{11} is less than A if R_2 is larger than its assumed minimum value.

For example if $R_2 \geq 0.1$ Ohm and $A = 0.8$ we calculate a frequency band from 12.6 to 14.2 GHz where the magnitude of S_{11} less then 0.8 if we use an extension line.

The length of extension line can be calculated from (2) and (4) using

$$K = \frac{Z_0 \tan\beta l}{1 - \omega C_2 Z_0 \tan\beta l} \tag{5}$$

In our example we have $l \approx 5.2$ mm. ($L_1 = 0.50$ nH; $L_2 = 0.70$ nH; $C_2 = 0.05$ pF and $C_4 = 0.20$ pF). In practice the effect of C_1 as a fringing capacitance is compensated by an extra length of line, so $l \approx 5.7$ mm.

REFERENCES

(1) Bianco,B. et al., Alta Frequenza 43, 1038 (1974)

(2) Getsinger,W.J., IEEE Trans. MTT-14, 56 (1966)

(3) Owens,R.P. et al., IEEE Trans. MTT-18, 790 (1970)